



NASA GSFC Strategic Nanotechnology Interests:

Symposium on High-rate Nanoscale Printing for Devices and Structures - Northeastern University, Burlington campus

Aprille Ericsson, Ph.D.

Deputy to the Chief Technologist,
Applied Engineering and Technology Directorate

NASA Goddard Space Flight Center

September 17, 2014



Agenda

- Where is NASA?
- NASA Goddard Space Flight Center (GSFC) Mission
- GSFC Nanotechnology Interests
- Avenues for Partnership with GSFC



Where is NASA?



NASA GSFC Facilities

- Goddard Space Flight Center, Maryland
- Wallops Flight Facility, Virginia
- Independent Validation & Verification Facility, West Virginia
- Goddard Institute for Space Studies, New York
- Ground Stations at White Sands Complex, New Mexico

WFF



WSGS



GSFC



GISS



IV&V

The Goddard Space Flight Center

NASA's 1st Space Flight Center (1959)

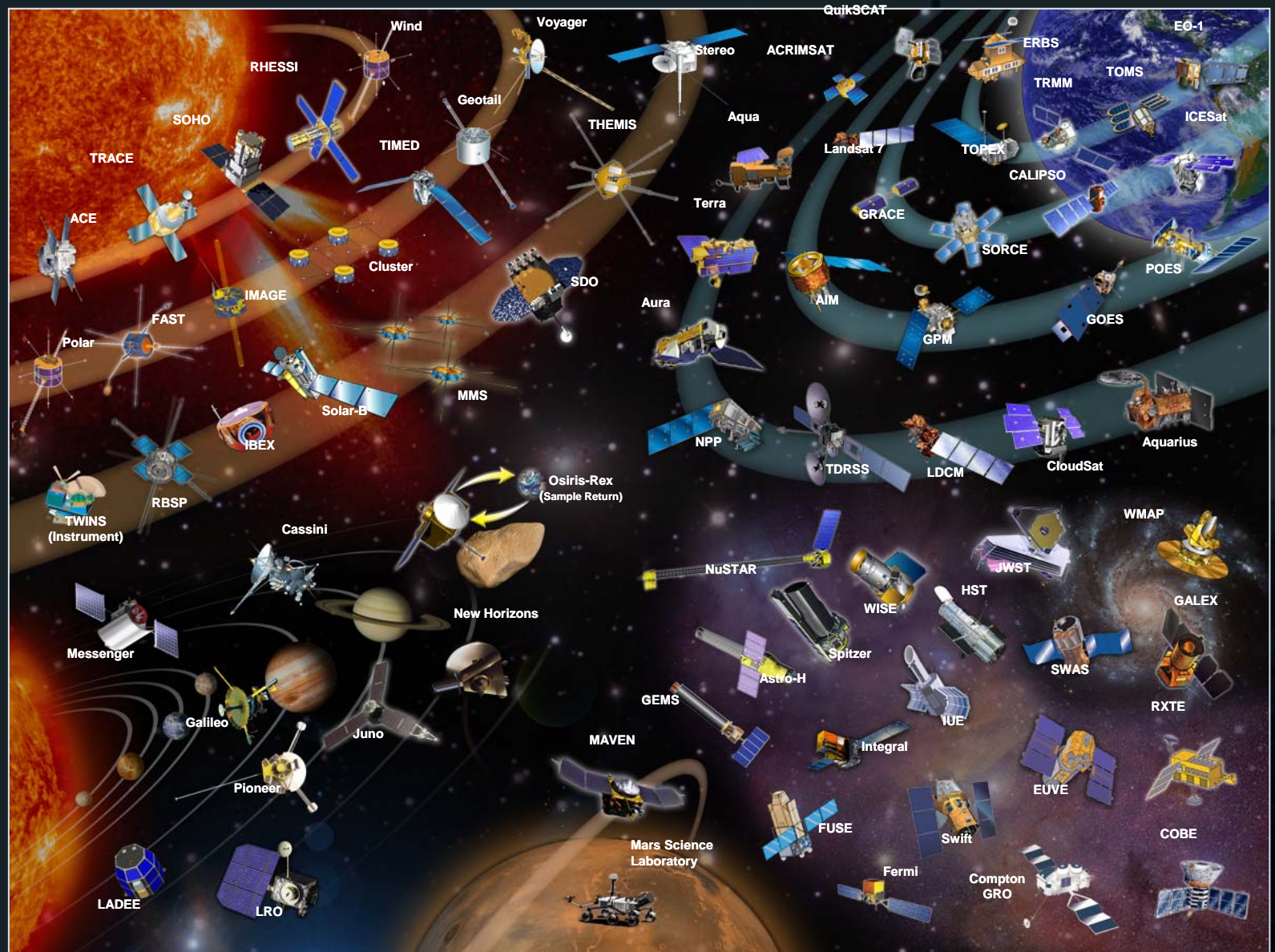
Our Mission: Address fundamental questions in Earth & Space Science

End-to-End Science and Technology Missions capabilities:

- Nearly 300 successful Missions – from the world's first weather satellite (1960) to Hubble Space Telescope servicing and beyond
- Nine spacecraft/instruments successfully launched in the last 2 years
- Conception, development, deployment, operation of science and technology missions in Earth system, planetary, heliophysics, and astrophysics disciplines
- Space/Near Earth Communications, Navigation and Network systems for NASA and National needs
- Suborbital Platforms and Launch Range Services
- Develop and advance innovative technologies
- Deliver data and information to the public in ways they can use it



NASA GSFC Contributions to Diverse Mission Portfolio



Engineering Technology Focuses



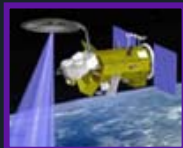
Laser Comm



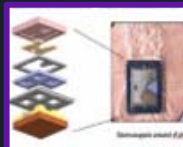
Detector Systems



Telescope Systems



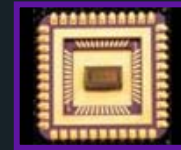
Microwave Sensing



Miniaturized Instruments



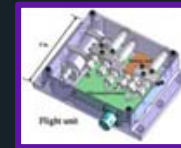
Collaborative and Intelligent Sensing for Situational Awareness



Extreme Environments



Integrated Avionics



Applied Nanotechnology



Composite Material Engineering



Flight Dynamics/Navigation



Communications

Enabling the "Reality of Tomorrow"

NASA Strategic Focuses

Nanotechnology

Engineered Materials & Structures

- Lightweight Structures
 - Fibers/Textiles
 - Membranes/Gossamer
 - Adaptive
 - Multifunctional
- Damage Tolerant Systems
 - Self-repairing materials
 - Self-diagnosing materials
 - Radiation Protection
 - EMI Protection
 - Antimicrobial
- Coatings
- Adhesives
- Thermal Protection and Control
 - TPS
 - Cryoinsulation

Energy Generation & Storage

- Energy Storage
 - Batteries
 - Ultracapacitors
 - Flywheels
 - Hydrogen storage
- Energy Generation
 - Fuel Cells
 - Photovoltaics
 - Thermophotovoltaics
 - Thermoelectrics
 - Piezoelectrics
 - Energy Harvesting

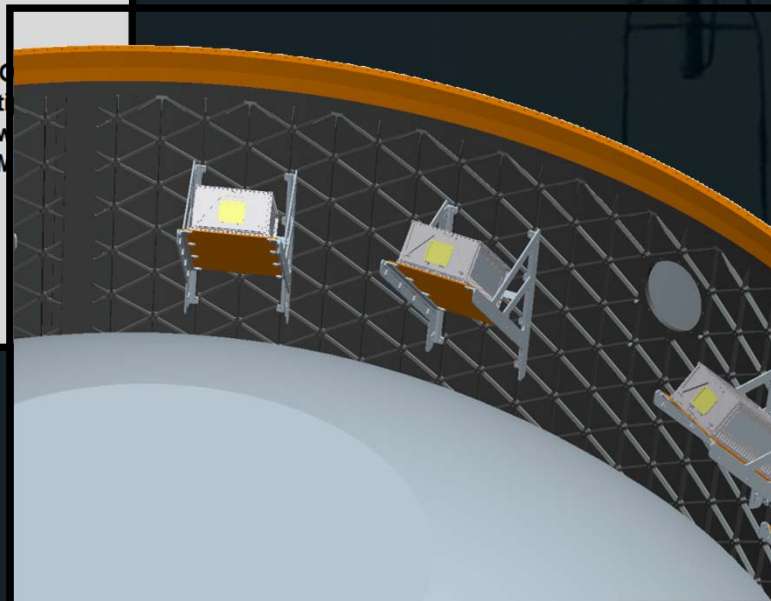
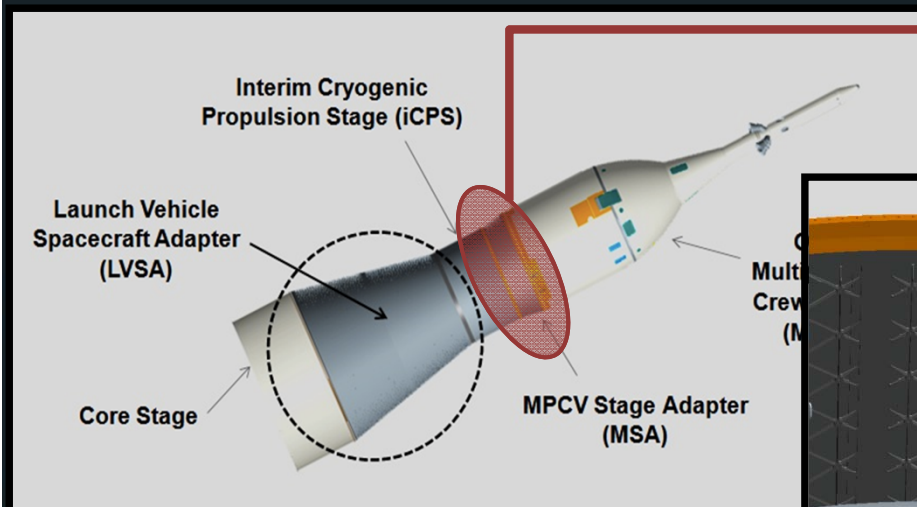
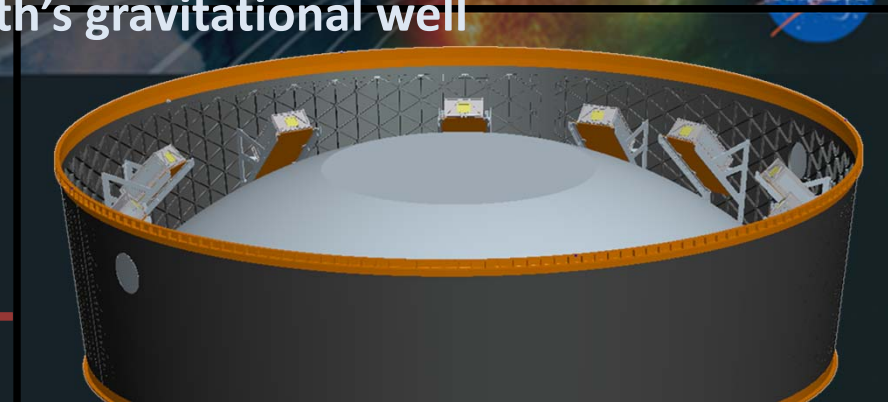
Propulsion

- Propellants
 - Monopropellants
 - Nanogelled Propellants
 - Hydrogen storage
- Propulsion Components
- In-Space
 - Electric
 - Solar Sails
 - Tethers

Sensors, Electronics & Devices

- Sensors and Actuators
 - Chemical
 - Biological
 - State
 - Astronaut Health Management
- Nanoelectronics
 - Graphene
 - Interconnects
 - Radiation Hardening
- Miniature Instruments
 - Emission Sources
 - Detectors
 - Spectrometers

Where no ~~man~~ has gone before (nano)satellite



End of mission

Moon

Orion- MPCV Spacecraft Adapter (MSA) on EM-1

- Capacity: ≤ 12 (6U) CubeSats
- Potential Destinations: Lunar, Solar, Planetary, Asteroids, Interplanetary,

ICPS under Power

Payload autonomous mission

Disposal Maneuver completion

<http://www.nasa.gov/sites/default/files/files/NAC-July2014-Hill-Creech-Final.pdf>

APPROVED

Integrating manufacturing techniques: Lead to the Miniaturization of Satellites



Assembled **CubeSat** satellite (left) and laser sintered parts (middle) CAD view of RAMPART with panels (right) (courtesy of CRP Technology, Italy)

<http://www.crptechnology.eu/aerospace-case-studies/>

20 internal parts made via **Additive Manufacturing** (AM) resulted in a reductions in: Cost of 60% and production time of 7 weeks.

<http://www.dst.se/gimbal/otus-u135>



Gimbal eye for aerial vehicle (left) and FDM parts (right) (courtesy of DST Control, Sweden)

Maturing AM Technology affords Miniaturization of Spacecraft Components



Liquid metal structures
(North Carolina State Univ.)

Courtesy: National Science Foundation

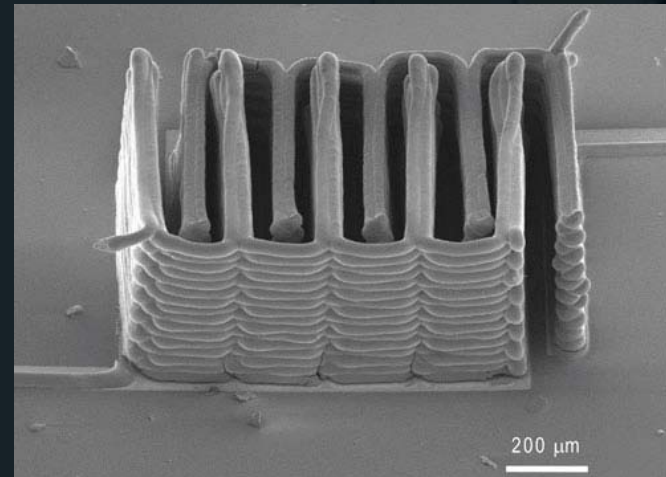
Stable, 3D printed structures made from liquid metal -- at room temperatures.

- The liquid metal, a gallium-indium alloy, forms a skin at room temperatures by reacting to the oxygen present in air.
- Shapes can be reconfigured.
- Four different processes were developed, including one for making wires

http://www.nsf.gov/news/mmg/mmg_disp.jsp?med_id=75722

3D printed micro-batteries

- The size of a grain of sand.
- Two different lithium-ion infused "Inks".
- Performance comparable to commercial batteries



3D printed battery: potential sensor application (Harvard Univ. & Univ. of IL)
(SEM image courtesy of Jennifer A. Lewis.)

<http://www.seas.harvard.edu/news/2013/06/printing-tiny-batteries>

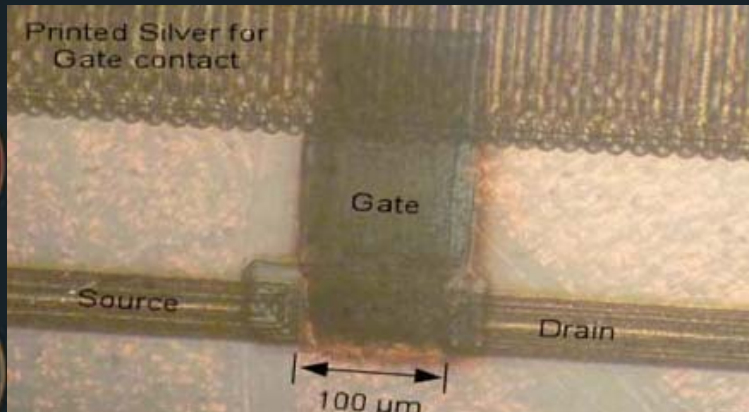
www.nasa.gov/goddard

Promising 3D Printing Application in Electronics

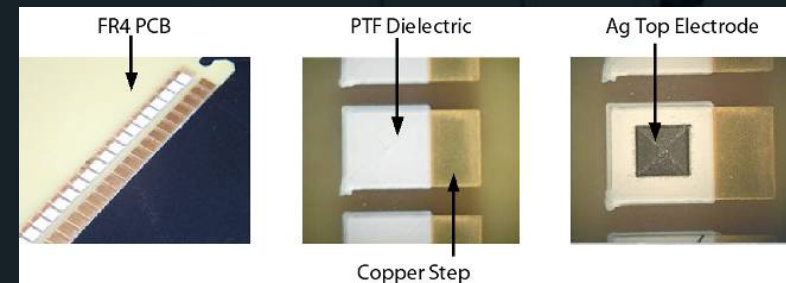
Demonstrated 3D manufacturing of various circuit building blocks, ie.,
Crossovers, Resistors, Capacitors, Chip Attachment, Power Sources, and
Active elements including TFTs.

Bring industry closer to 'printing everything', including Biological Circuits.

Optomec's aerosol jet thin-film conformal printing process can print a broad spectrum of conformal functional circuitry, including sensors, EMI shielding, antennas, and a variety of active and passive components, and COTS attachment technology.



Printed CNT thin film transistors (Optomec)



Multi-layer deposition, Polyimide dielectric and Ag deposited onto Cu pads to make a simple capacitor

Currently, GSFC evaluating the viability of aerosol jet printing technology for spaceflight electronics applications.

Budding Nanodetectors: Partnership with NEU and GSFC

GSFC PI: M. Sultana/553

Objective:

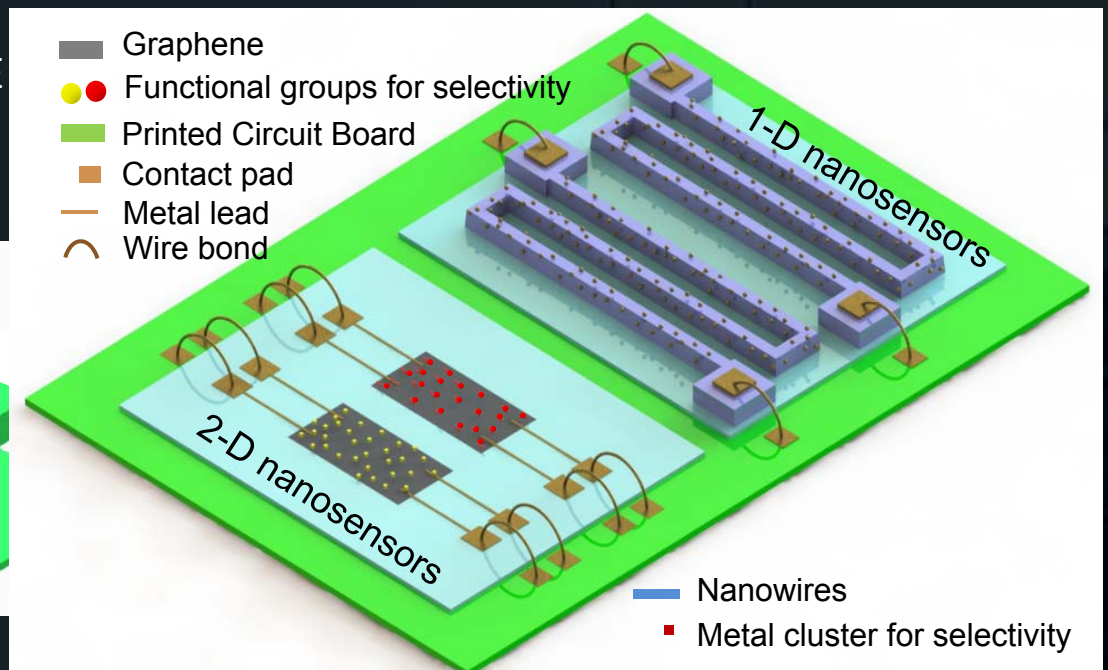
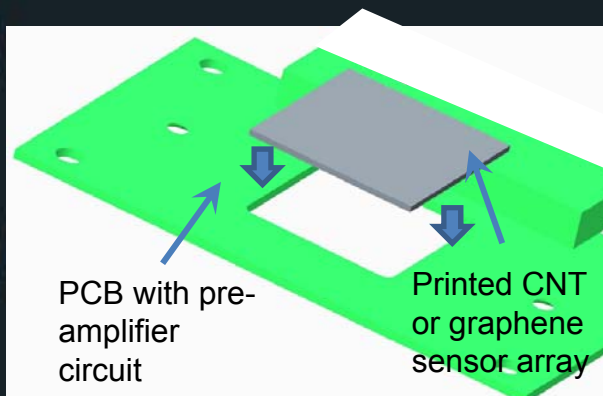
To print out nanosensors and their leads using 3-D printing techniques on a daughter board that can be connected to a self-contained pre-amp PCB.

Innovation:

Will significantly increase the signal, and thus the sensitivity, and enable the detection of minute concentration of gases (e.g. ppb level or possibly single molecule, which is unprecedented)

Applications:

Planetary & Earth science, DOE



<http://gsfctechnology.gsfc.nasa.gov/newsletter/Fall%202012Current.pdf>

Miniaturizing Telescopes through 3D Printing

GSFC PI: Budinoff/544

Objectives:

Utilize new direct metal laser sintering (DMLS) to produce dimensionally stable integrated instrument structures at lower cost

- Demonstration of DMLS fabrication of integrated metallic telescope and optical benches
- Demonstration of hybrid composite/DMLS metallic/glass instrument structures

Innovation:

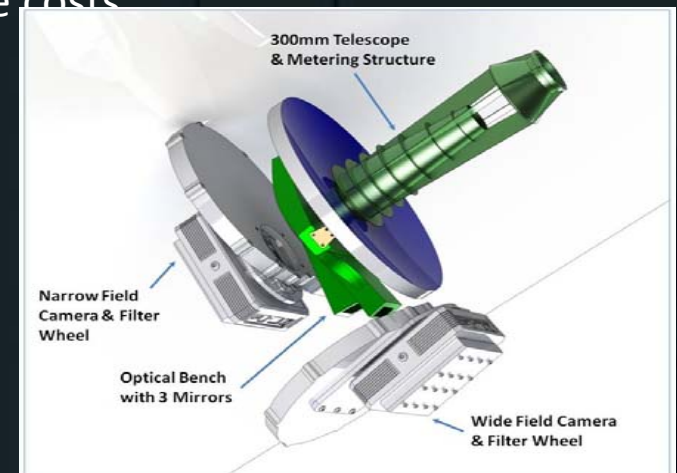
Creating thin-walled structures in flight instruments is a challenge when using this technique. Build direction, post build heat treatments, and machined removal of build support structures are engineering challenges which must be overcome so future flight programs will avoid these costs

Applications:

Small Space flight Optics and Telescopes



CubeSat-class 50-mm (2") imaging camera/instrument -mirrors and integrated optical-mechanical structures- manufacturing with 3D-printed parts (J.Budinoff)



0.3m Telescope via DMLS for a 1U CubeSat Imager

AM for Stable Light-weight Small Structures

GSFC PI: Tim Stephenson/541

Objectives:

Develop new alloys and apply advanced manufacturing techniques to improve dimensional stability and lower mass. We have four efforts using the Fe-Ni binary system as a model:

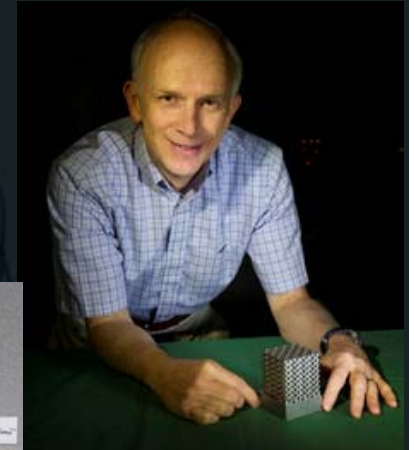
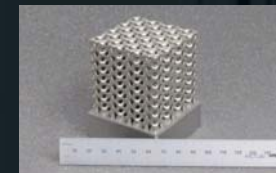
- Invar® Metal Matrix Composites
- Engineered structures based on the AD paradigm
- Tailored composition for microstrain (CTE) matching
- Combined approached for hybrid structures

Innovation:

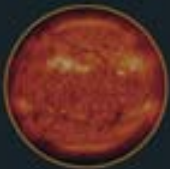
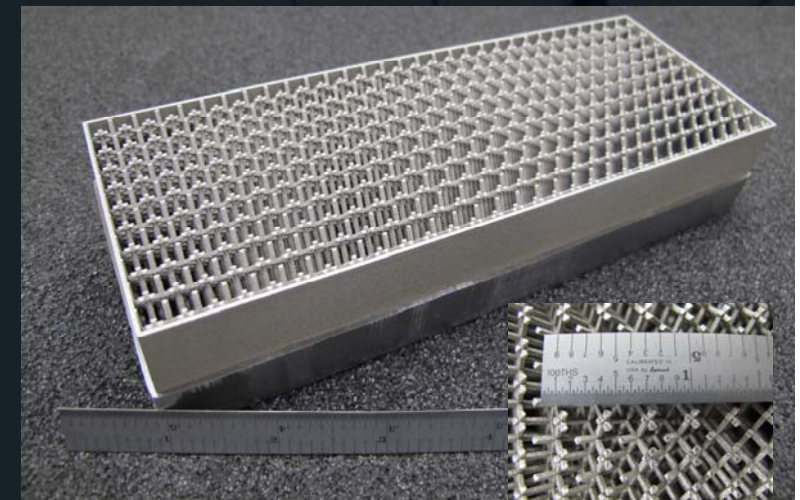
Never-before-attempted manufacturing techniques with new alloy compositions for proof-of-concept novel structures. The innovation resides in coupling these 2 approaches to make hybrid, compositionally graded structures

Applications:

Ensures stable, lighter weight structures for optical benches, precision optics and sensors for all future missions



The **first** time Invar® structure ever produced by DMLS, and the GRID 45 structure had been fabricated from metal . (NASA GSFC FY13 IRAD)



Evolving Strong Micro Unit Structures

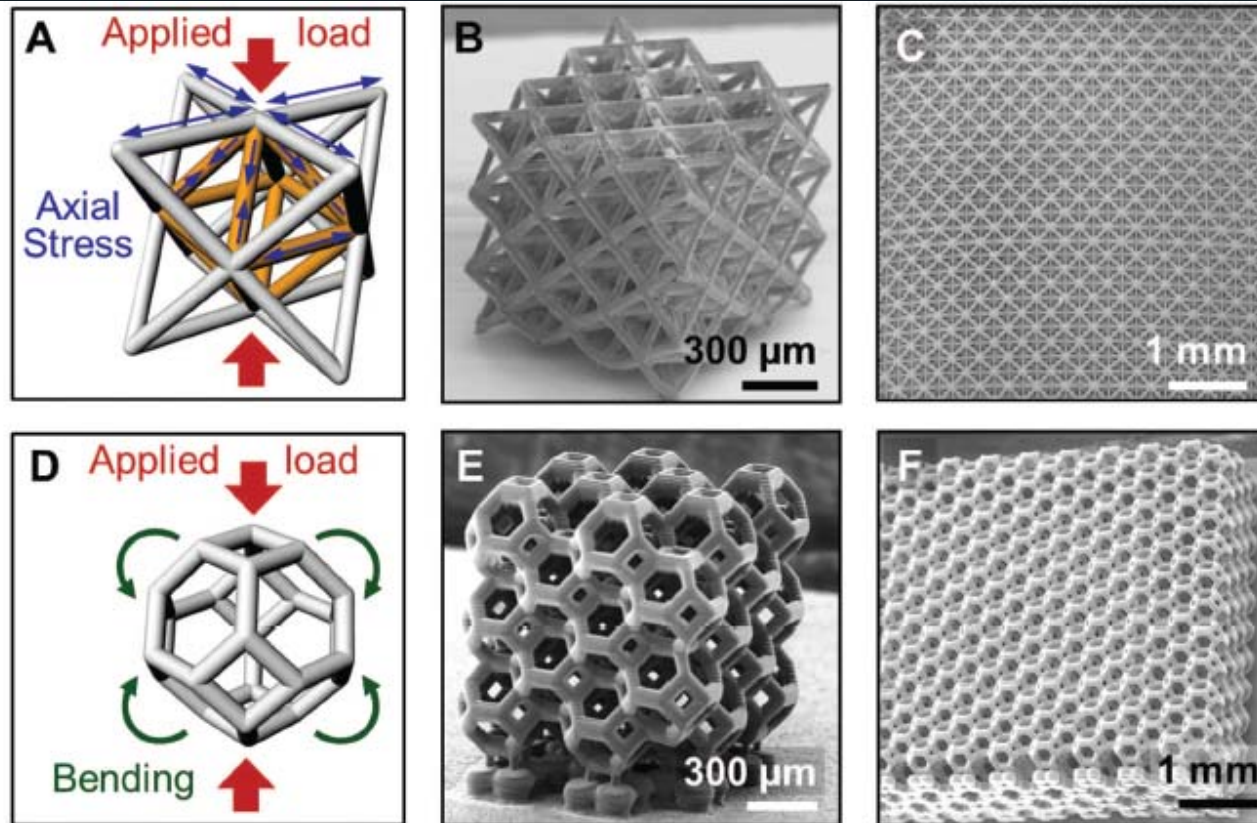


Fig. 1. Architecture of stretch-dominated and bend-dominated unit cells and lattices. (A) Mechanical response to compressive loading of a stretch-dominated octet-truss unit cell. (B) Octet-truss unit cells packed into a cubic microlattice. (C) SEM image of a stretch-dominated lattice material composed of a network of octet-truss unit cells. (D) Mechanical response to compressive loading of a bend-dominated tetrakaidecahedron unit cell. (E) Tetrakaidecahedron unit cell packed into a cubic bend-dominated lattice (Kelvin foam). (F) SEM image of a bend-dominated lattice composed of a network of tetrakaidecahedron unit cells.

Objective:

Ultralight, Ultrastiff Mechanical Metamaterials are made possible by projection microstereolithography (an AD technique) combined with nanoscale coating and postprocessing.

Innovation:

Microarchitected materials that maintain a nearly constant stiffness per unit mass density even at ultralow density. This performance derives from a network of nearly isotropic microscale unit cells with high structural connectivity and nanoscale features, whose structural members are designed to carry loads in tension or compression.

Applications:

- Structures needing high stiffness, dimensional stability, and low weight, i.e., Mirror backplanes, optical benches.
- If these elements had electrical conductivity (or a dipole moment), they could be mixed into a coating to turn a surface into an antennae or possible a detector.

LLNL (source Sciencemag.org)

<http://www.sciencemag.org/content/344/6190/1373.full.pdf?sid=390ff405-b3ee-4f61-ad3d-9d5a47dfe955>

Objective:

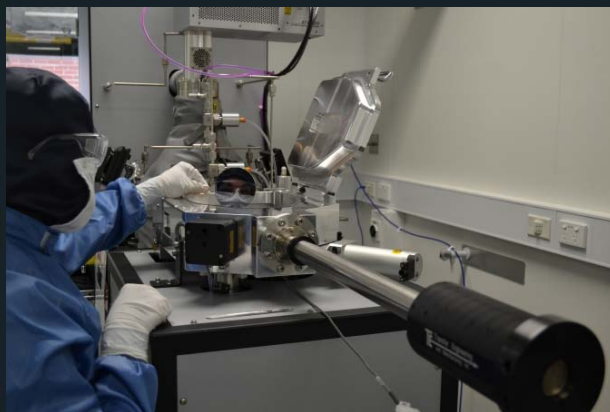
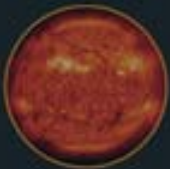
Atomic Layer Deposition (ALD) is one of many techniques for applying thin films. Australia Melbourne Centre for Nanofabrication (MCN) fine-tuned the recipe for laying down the catalyst layer (detailing the precursor gas, the reactor temperature and pressure) needed to deposit a uniform foundation.

Innovation:

Technicians can accurately control the thickness and composition of the deposited films, even deep inside pores and cavities thus the unique ability to coat in and around 3D objects.

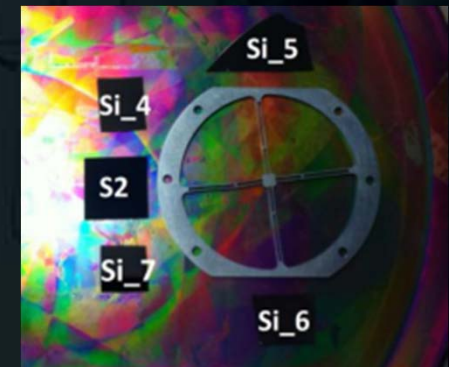
Application:

GSFC and UMD are now advancing ALD reactor technology customized for spaceflight applications. GSFC has successfully grown carbon nanotubes on the samples provided to MCN. They demonstrate properties very similar to those grown using other techniques. Our ultimate goal of applying a carbon-nanotube coating to complex instrument parts is nearly realized.



Lachlan Hyde, an ALD expert at Australia's MCN, works with one of the organization's two ALD systems (left)

Australia's MCN applied a catalyst layer using atomic layer deposition to this occulter mask. (right)



Objective:

Desire Spacecraft instruments more sensitive without enlarging their size. Demonstrated growth of a uniform layer of carbon nanotubes through the use of ALD.

Innovation:

Marriage of the two technologies allows NASA to grow nanotubes on 3-D components, such as complex baffles and tubes commonly used in optical instruments

Applications:

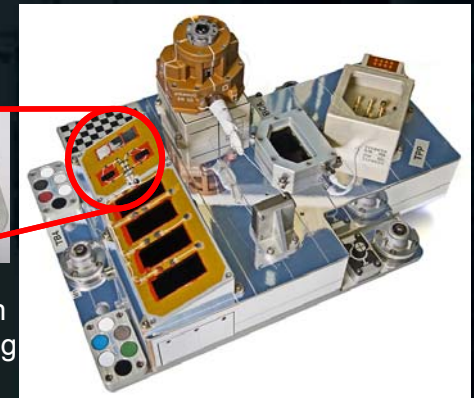
- Cubesats, a class of less-expensive tiny satellites called reduce the cost of space –science- missions.
- Suppression of stray light that can overwhelm faint signals that sensitive detectors are supposed to retrieve

Carbon-nanotube coating is one of the materials to be tested on the International Space Station as part of the Materials Coating Experiment. The super-black material occupies the “D” slot on the sample tray.

Robotic Refueling Mission-Phase 2 task board that will be installed on the orbital outpost’s Express Logistics Carrier 4. The Materials Coating Experiment can be seen on the left.



J. Hagopian works with a nanotube material sample



Goddard Partnerships

- International
 - In Flight Projects, work with >19 foreign countries
 - Experience in integrating foreign hardware
- Interagency
 - Working with 17 federal entities, for example:
 - Joint weather satellite programs with NOAA and DoD
 - Landsat with DOI/USGS
 - Relationship with NRL since GSFC was formed
 - Partnership with the JHU Applied Physics Lab on Sun-Earth Connection
 - DOE on WFIRST, Fermi Space Telescope
- Universities
 - Currently involve >30 national and international universities in mission development
 - Multiple additional agreements exist to support science and research
- Other NASA Centers
 - We work with and have good partnerships with other Centers



Avenues for Partnership with GSFC

Points of Contact:

- Procurement Office by telephone at 301-286-4379, or visit its Web Site:
<http://code210.gsfc.nasa.gov/procure.htm> (NASA Acquisition Internet Service)
 - Announcements of Opportunity – Business Commerce Daily
 - Most contracts will depend on each Announcement
 - Subcontractor through Major contracts as a Task
 - Innovative Technology Partnerships Office (ITPO) call the general Technology Line at 301-286-5810 or visit the Web site at <http://ipp.gsfc.nasa.gov/> for information about available technologies and important resources for partnerships and licensing
 - Small Business Innovative/Technology Research – SBIR/STTR
- University Opportunity
 - STTR
 - Space Grant Offices
 - University Programs Office
 - One Stop Shopping Initiative
 - <https://intern.nasa.gov/>



Contacts for funded Partnerships

Innovative Technology Partnerships
Office (ITPO)

Small Business Innovative Research/
Small Business Tech Transfer Research
(SBIR/STTR)

Enidia Santiago-Arce

Tech Transfer Manager

enidia.santiago-arce@nasa.gov

301-286-8497



ITPO Website:

<http://itpo.gsfc.nasa.gov>

Ramsey Smith

Deputy SBIR/STTR Manager

ramsey.l.smith@nasa.gov

301-286-5974



NASA SBIR/STTR Website:

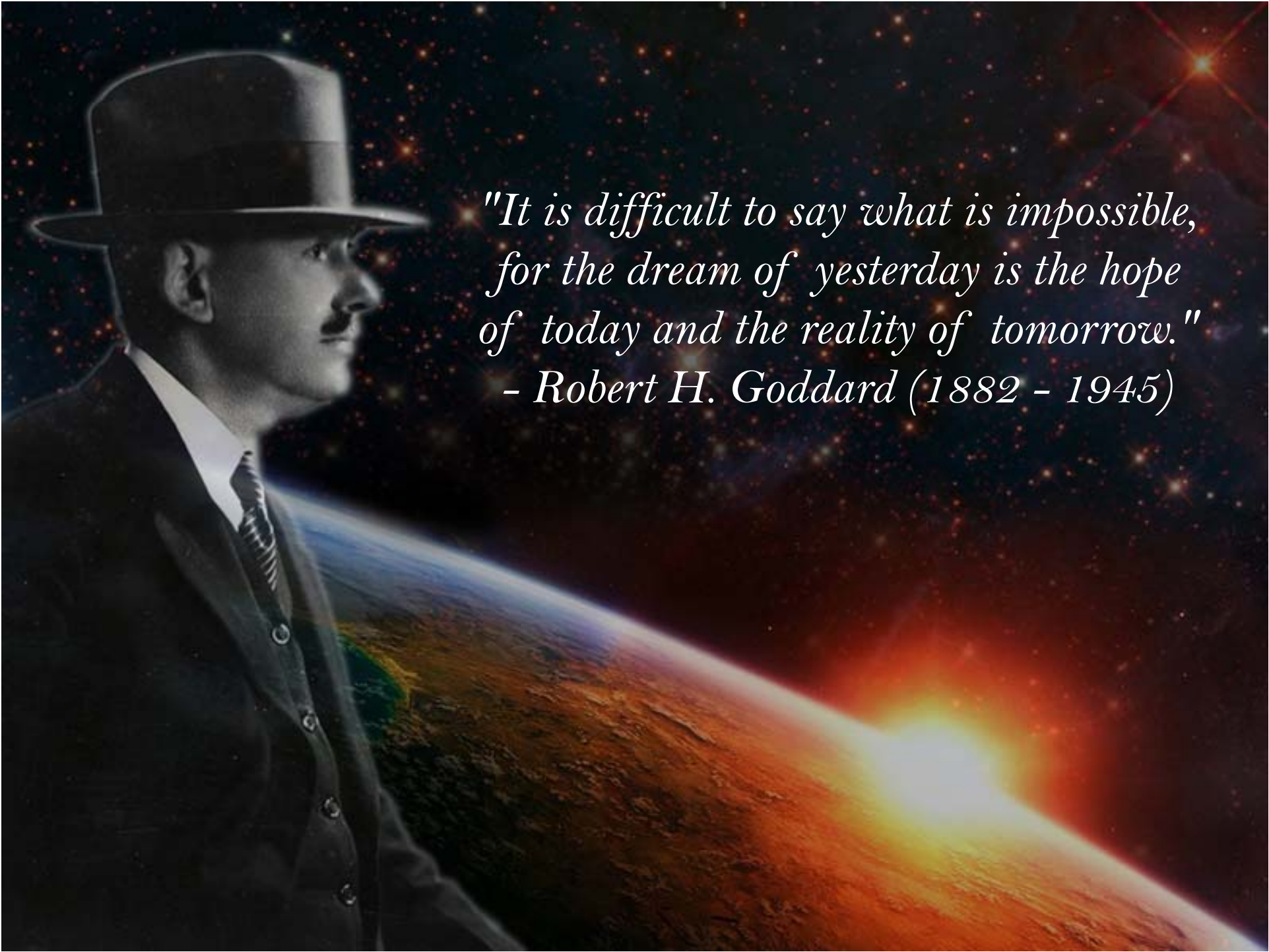
<http://sbir.nasa.gov>



NASA/GSFC Educational Opportunities

HIGHER Education :	Ms. Mablelene Burrell	Mablelene.A.Burrell@nasa.gov
Contacts:	Ms. Janie Nall	Janie.M.Nall@nasa.gov
	Ms. Raquel Marshall	Raquel.H.Marshall@nasa.gov
OSSI Administrator:	Mr. Dave Rosage	David.J.Rosage@nasa.gov
To Apply:	https://intern.nasa.gov	
2015 Internships Session Milestones:		
Spring '15	Application Open Date	June 2, 2014
	Application Closing Date	October 12, 2014
	Spring Internship period:	Jan 12 – April 24, 2015
Summer '15	Application Open Date	November 1, 2014
	Application Closing Date	March 1, 2015
	Summer College Internship period:	June 1 – Aug 7, 2015
Fall '15	Application Open Date	March 2, 2015
	Application Closing Date	June 1, 2015
	Fall Internship period	Aug 24 – Dec 11, 2015
Massachusetts Space Grant Consortium Contacts:		
Director:	Dr. Jeffrey Hoffman	jhoffma1@mit.edu
Co-Director:	Ms. Raji Patel	rpatel@mit.edu
Program Administrator:	Ms. Helen Halaris	halaris@mit.edu



A composite image featuring a black and white portrait of Robert H. Goddard on the left. He is wearing a dark suit, a white shirt, a striped tie, and a fedora hat. He is looking out of a circular porthole towards the right. Outside the porthole, a vibrant view of Earth from space is visible, showing the blue and white horizon of the planet against a dark, star-filled background. A bright, glowing sun or star is visible in the lower right corner, casting a warm orange and yellow light across the scene.

*"It is difficult to say what is impossible,
for the dream of yesterday is the hope
of today and the reality of tomorrow."
- Robert H. Goddard (1882 - 1945)*



BACKUP



NASA (1958)



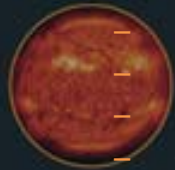
- NASA Headquarters, Washington, DC
 - exercises management over the space flight centers, research centers, and other installations that constitute NASA.
- Ames Research Center, Moffett Field, CA (South San Francisco Bay Area in the heart of Silicon Valley)
 - Founded in 1939 as an aircraft research laboratory by the NACA, it became part of NASA in 1958. Its research is geared toward creating new knowledge and new technologies.
- Dryden Flight Research Center on Edwards AFB, CA (~2 hrs north of Los Angeles, CA)
 - is NASA's primary installation for flight research in the design and development of capabilities of many civilian and military aircraft.
- Glenn Research Center at Lewis Field, Cleveland, Ohio
 - Open since 1941, it is responsible for developing and transferring critical technologies in aeropropulsion and space applications. Research focused on new aeropropulsion technologies, aerospace power, microgravity science, electric propulsion, and communications technologies for aeronautics, space, and aerospace applications.
- Goddard Space Flight Center, Greenbelt, MD (15 miles east of W.D.C.)
 - Established in 1958, is to expand knowledge of the Earth and its environment, the solar system and the universe through observations from space. Supports the implementation of the programmatic strategies of Earth and Space Science enterprises.
 - Goddard Institute Space Studies, NY, NY; Wallops Flight Facility, Wallops Island, VA (on Virginia's Eastern Shore); Independent Verification & validation facility (IV&V Facility), Fairmont, WV
- Jet Propulsion Laboratory, Pasadena, CA (near Los Angeles, CA)
 - NASA federally funded research and development center operated by Caltech. It is the primary center for planetary science and exploration, and lead center for Earth Science instrument technology.
- Johnson Space Center, Houston, TX
 - Established in 1961, leads NASA's efforts in human space exploration.
 - White Sands Test Facility, NM - resource for testing and evaluating potentially hazardous materials, space flight components, and rocket propulsion systems.
- Kennedy Space Center, Cape Canaveral, FL (east of Orlando, FL)
 - Is the departure site for the first human journey to the moon; the starting point for hundreds of scientific, commercial, and applications spacecraft; and as the base for Space Shuttle launch and landing operations.
- Langley Research Center, Hampton, VA
 - Established in 1917, as the nation's first civilian aeronautics laboratory. It leads NASA initiatives in aviation safety, quiet aircraft technology, small aircraft transportation and aerospace vehicles system technology.
- Marshall Space Flight Center, Huntsville, AL
 - Has been supporting launch vehicle development since 1961, it continues to support all of the NASA enterprises today.
- Stennis Space Center, Bay St. Louis, MS
 - is responsible for NASA's rocket propulsion testing and for partnering with industry to develop and implement remote sensing technology.



Engineering and Technology Expertise

1. End-to end mission system design and implementation:

- Thermal Systems
- Large Optical Systems
- Environmental Testing
- Flight Dynamics Analysis
- Spacecraft Propulsion
- Mechanical Structures/Mechanisms
- Mission Systems Engineering & Implementation
- Avionics Architecture & Implementation
- RF & Optical Communication Systems
- Command & Data Handling Systems
- Power Systems & Electrical Systems
- Ground Support Equipment Design & Implementation
- Guidance, Navigation & Control Components & Systems
- Flight & Ground Software Systems
- Systems Integration, Test & Verification
- Access to Space Carrier Systems
- Ground Command & Control Systems
- Mission Planning & Scheduling Systems
- Data Processing, Analysis & Modeling Systems



2. Engineering competencies in support of scientific instrumentation:

- Detector Systems
- Optics, Lasers & Electro Optics
- Cryogenics & Fluids Systems
- Active/Passive Microwave Systems
- Payload/Instrument Management & Systems Engineering

3. Cross-cutting engineering disciplines:

- Materials
- Autonomy
- Contamination Control
- Electromechanical Systems
- Wavefront Sensing & Control
- Electronics Parts & Radiation
- Data Management & Analysis
- Microelectronics & Signal Processing
- Machining/Fabrication Technologies
- Network Systems & Technology
- Computing Environments & Technologies

Applied Engineering and Technology
Directorate—Enabling the “Reality of
Tomorrow”

The Applied Engineering & Technology Directorate

AETD provides end-to-end engineering support to all projects within GSFC focusing on the following areas:

Earth and Space

- State of the art scientific instruments
- Sub-orbital to orbital scope scientific missions
- Flagship scientific observatories missions
- End-to-end data systems

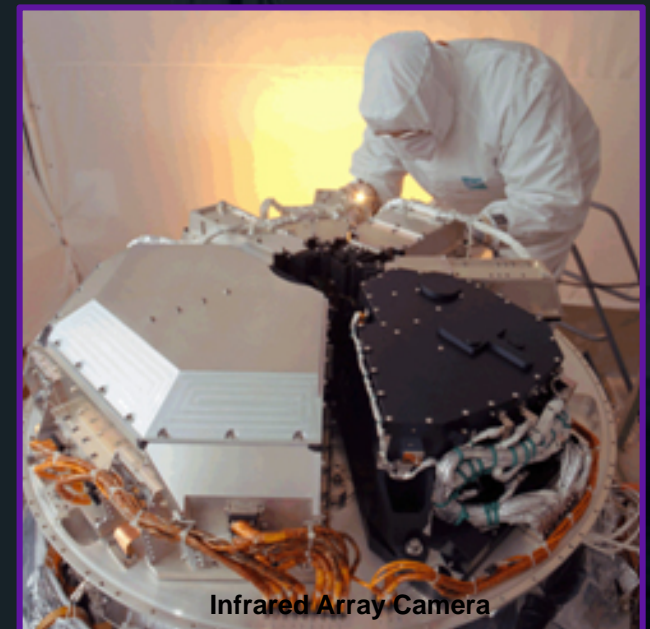
Exploration

- Avionics systems communications and navigation
- Situational awareness and decision-making tools

Space Operations

- Flight Dynamics Facility and navigation systems
- Ground and space communications network
- Operations systems

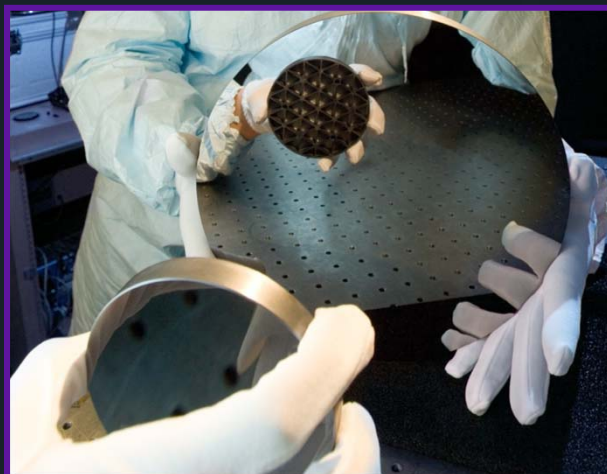
We develop high performance and cost effective solutions to the most challenging problems on flight missions ranging from suborbital projects—including balloons, sounding rockets, and airplanes—to interplanetary probes and flagship observatories. In addition, we acquire and distribute science data worldwide.



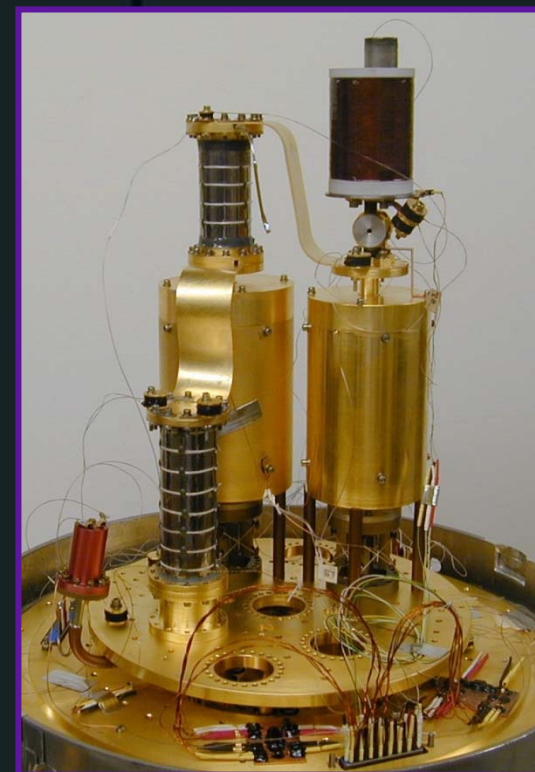
Instrument & Missions Systems Technology



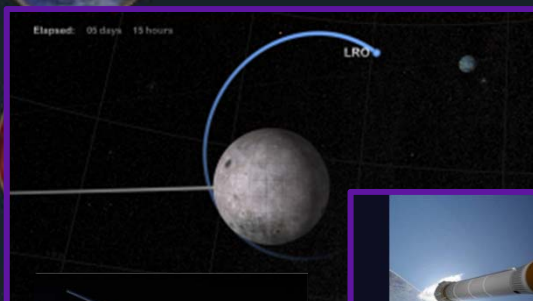
JWST



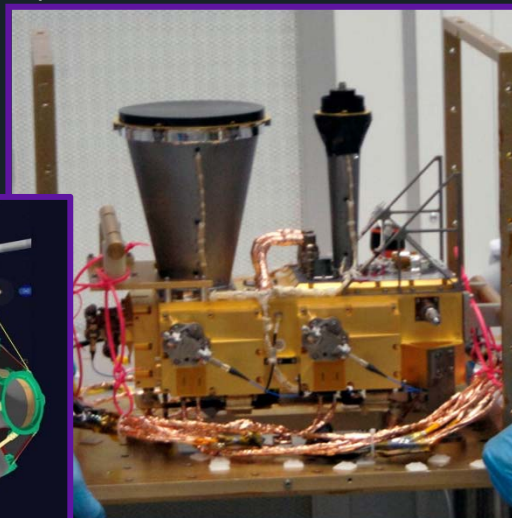
Optics



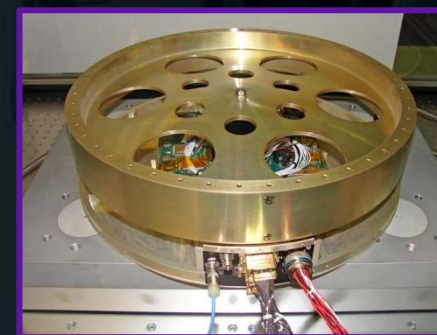
mK Temp



CubeSat - SmallSat



Lasers



Enabling the "Reality of Tomorrow"

Program	How the ITPO Works with Internal Inventors	How the ITPO Works With External Partners
Technology Transfer	<ul style="list-style-type: none"> • Harvest inventions • Secure intellectual property protection • Market inventions • Facilitate agreements with industry 	<ul style="list-style-type: none"> • Provide access to invention portfolio • Communicate IP protection status • Highlight technologies for license • Facilitate agreements with NASA
SBIR/STTR	<ul style="list-style-type: none"> • Harvest R&D need topics • Facilitate awards & project management 	<ul style="list-style-type: none"> • Announce SBIR/STTR opportunities • Facilitate project management
Partnerships	<ul style="list-style-type: none"> • Brainstorm needs with researchers and downselect to topics for pursuit • Market to target parties • Facilitate partnership with industry 	<ul style="list-style-type: none"> • Make external parties aware of collaborative opportunities • Aid interactions with inventors • Facilitate partnership with NASA

<http://itpo.gsfc.nasa.gov/about-itpo/mission-programs/>

Partnership Process

Objective	Purpose	Outcome
Integrate Ideas	<ul style="list-style-type: none"> Share unique products and processes Avoid reinventing what has already been done Build on expertise 	<ul style="list-style-type: none"> Build new relationships Advance state-of-the art Future consideration for other technical challenges
Leverage Resources	<ul style="list-style-type: none"> Capture mutually needed resources Collaborate vs make Take advantage of shared resources to afford other needs 	<ul style="list-style-type: none"> Savings of funding and R&D Address limited resources Value add for meeting critical needs
Accelerate Development of End Products	<ul style="list-style-type: none"> Proof of concept in a timely manner 	<ul style="list-style-type: none"> Quicker solution to technology needs Advance overall mutual project needs Proof of faster, better at a cost savings to both parties

Bottom Line = Win for Partnership Team for Future Collective R&D Opportunities